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Human Factors Applied to Perioperative Process Improvement

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KEYWORDS

• Human factors • Medical errors • Safety • Information processing
• Bias and decision making • Performance assessment • Stress and fatigue

KEY POINTS

- Human factors/ergonomics (HF/E) is its own scientific discipline that can be applied to understanding performance in perioperative medicine.
- Humans are not perfect decision makers and are affected by a variety of factors that can greatly harm their ability to perform, including attention, bias, stress, and fatigue.
- HF/E has a unique perspective on human error, and HF/E can illustrate how moving away from blame can enhance safety.
- HF/E offers strategies for undertaking a systematic approach to assessment of work processes in perioperative medicine that can be used to increase safety and wellbeing of patients and providers.

OVERVIEW OF HUMAN FACTORS AND ERGONOMICS

Human factors and ergonomics (HF/E) is a multidisciplinary scientific field that lies at the cross-section of engineering, psychology, safety, and design.[1] HF/E focuses on the relationship between humans and technology at work and attempts to make these human-machine systems safe, reliable, and enjoyable. To accomplish these goals, HF/E considers the design of tasks, equipment, the operational environment, and the training and selection of personnel. Although there has been HF/E work in medicine for decades, only recently has HF/E begun to be integrated on a wide scale

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into the medical domain. After reports by the Institute of Medicine[2] and more recently by Makary and Daniel[3] highlighting the danger of medical errors and the numerous patient deaths resulting from them, it is pertinent that medical systems' safety is improved. Therefore, this article focuses on the application of HF/E to the medical domain and, more specifically, the perioperative environment. Some of the major theories of HF/E and how they can be applied to understanding the medical work environment are highlighted. The aim is to provide a grounded discussion of the HF/E science within this context and demonstrate the way it can be leveraged to make the perioperative environment as safe as possible. Within each section is detailed a major component of HF/E, and examples are provided from the perioperative environment where appropriate. Finally, suggested remedial strategies based on the various aspects of HF/E discussed are summarized.

HUMAN COGNITION AND PERFORMANCE

To understand work systems, how human beings think and act must be understood. One of the core theories behind how human cognition functions — in other words, how individuals perceive, attend to, and evaluate information from the world — is called *information processing*.[4] Information processing theory (**Fig. 1**) breaks human cognitive capabilities into its constituent parts. These include understanding attentional capacity, perceptual limitations, working and long-term memory storage and recall, and decision-making mechanisms.

Referring to **Fig. 1**, energy from the world — be it light (vision), sound waves (hearing), or pressure (feeling) — enters the various sensory organs and creates a signal. Next, the energy is processed through attentional mechanisms. *Attention* is the process of controlling — either consciously or unconsciously — the limited sensory mechanisms to focus on important information and ignore irrelevant or unimportant information.[5] This information then enters *perception*, which is the interpretation of energy from the world into a meaningful whole and is limited by the filters of attentional mechanisms. *Memory* refers to 2 systems — *working memory*, which is the active cognitive mechanisms, in which information is temporarily stored for use in the near future, and *long-term memory*, which is a repository for the majority of important memories across the life span. Finally, there is *decision making*, which consists of choosing and executing a plan of action based on the attenuated perceptual process and previous experiences.

Human cognition functions by using 2 parallel yet distinct systems for processing information — a perceptually driven system, usually referred to as *bottom-up processing*, and an expertise-driven and memory-driven system referred to as *top-down processing*.[6] These 2 systems work in tandem to lead to conscious experience of the world, yet both are error prone and problematic in certain circumstances. Bottom-up processing uses direct information from the world and is error prone when that information is incomplete — such as when individuals are experiencing high workload, have difficult decisions with multiple potential outcomes, or lack knowledge about a particular situation. Top-down processing uses memory and sums of knowledge to make educated guesses about the world. It relies on experience to make judgments

Fig. 1. Basic model of information processing in human cognition.

that can sometimes override direct experiences. As an example, imagine a provider hearing an alarm for the first time that alerts the provider to changes in a patient's health status. This normally would instantly grab attention and is an example of the bottom-up mechanism of cognition. But imagine a situation where the alarm is constant — or is one that beeps regularly on a machine a provider has been using for years. Instead, the provider will likely ignore it, having become accustomed to the noise always present.

The information processing model is important to consider in the perioperative environment because it explains numerous issues arising from the cognitive work of medical professionals. Medical providers are inundated with large amounts of information and must make complex and snap decisions in a work environment full of noise and distractions. Two examples of how information processing can be involved in accidents and the issues that can arise from information processing failures and how they relate to the perioperative environment are highlighted.

Selective Attention

Many failures in human performance are related to attention. Specifically, *selective attention* can undermine the ability to make decisions correctly under moments of high workload or pressure. For instance, a majority of car accidents and incidents involving controlled flight into terrain are arguably caused by selective attention limitations.[1] In health care, providers are inundated with information from electronic medical records (EMRs), colleagues, and monitors as well as alarms, overhead announcements, and a multitude of information from other sources. Therefore, providers are always actively selecting what is important to attend to within their work environment. This has important implications for errors. Can providers be blamed for failures in attention when they are constantly bombarded by various signals from a multitude of sources? Regardless of professional expertise, human beings do not function well in this type of system due to selective attention. It is important for organizations to recognize that all humans have these attentional limitations and to allow for work design that remediates inundating individuals with too much information.

Prospective Memory

Often, providers rely on their memory to keep a to-do list for the work they have to conduct throughout their day. Unfortunately, relying on this type of memory, often termed, *prospective memory* — remembering to remember — can lead to errors in performance. Prospective memory relies heavily on cues — for instance, delivering a drug when a particular alarm sounds — or relies on time — giving a dose of a drug every hour.[7] Both of these processes can suffer heavily from interruptions or off-task activity, leading to major failures in providers keeping to the list in their prospective memory. A common way to counter prospective memory failures is using checklists and other cognitive aids — physical artifacts that act as memory outside of the head. Although little work has directly examined the effects of protocols or checklists on prospective memory performance, much of the work on handovers and transitions of care has found that use of checklists is an effective way to pass large amounts of patient information quickly.[8] Therefore, it makes sense that using these types of tools would remediate the issues that arise from relying too heavily on prospective memory mechanisms.

Decision Making and Bias

Humans can only understand the world through their limited perceptual mechanisms, as described previously. Although it was previously thought that decisions were made by evaluating and weighing each potential option (ie, the normative model of decision making),[9] work by Tversky and Kahneman[10] and decision making scientists over the past 4 decades has instead demonstrated that human decisions are affected by a plethora of biases. Biases are defined as errors in thinking that are based in the limited ability to attend to and process information as well as previous experiences and judgments of the world.

There are numerous biases that can affect work in the perioperative environment (**Table 1**). Many are based in the inability to perceive all information in the world concurrently. Instead, humans make decisions that are based on oversimplified mental simulations of reality,[11] sometimes called heuristics. *Bounded rationality* refers to the state of thinking within the limitations of human perceptual capabilities. In other words, humans attempt to be as rational as possible given limited knowledge, attention, and ability to understand the outcomes of complex decisions. Within the perioperative environment, it is important to consider this bounded rationality when considering blame and the way individuals work. This idea that individuals — acting as bounded rational thinkers — are attempting to do their best in an incomplete and risky world is referred to as the *local rationality principle*. Individuals usually make decisions to the best of their ability yet fail against their best interest.[7] **Table 1** describes some of the most common biases that affect human decision making and offers examples of how these biases may play out in the perioperative setting.

Bias has can be countered in a multitude of ways. Robbins[12] lists some potential remedies. These include staying targeted on goals; seeking information from multiple sources, especially those that might counter values or beliefs; acknowledging and avoiding the formation of causal relationships from random data; and increasing options when making decisions.

STRESS AND WORKLOAD

The health care domain is rife with examples of humans working under high stakes with conditions, such as time pressure, uncertainty, and complex technology; the perioperative environment is no different. Working under stressful conditions can generate negative psychological and physiologic responses, which, in turn, can have both short-term and long-term negative impacts on job performance as well as providers' overall health and well-being.

Stress

The term, *stress*, is used in HF/E to describe the process by which external demands (eg, time pressure, events, and noise) evoke a self-appraisal process in which perceived demands exceed resources, resulting in undesirable physiologic, psychological, behavioral, or social outcomes.[13] **Fig. 2** portrays the relationship between level of arousal induced by stressors and performance.[1] As can be seen, the relationship is an inverted U function. In situations of low arousal (in which the worker is not fully stimulated and bored/not alert), performance tends to be poor. As stimulation increases to a moderate level, performance also improves, until arousal has increased beyond a certain degree, at which point performance begins to drop off.

Over the long term, stress-induced physiologic changes can damage health via effects on the nervous, cardiovascular, endocrine, and immune systems.[14] In addition to long-term decrements in physical health, more immediate impact occurs on job performance,[15] some of these via cognitive effects.[16] Consequently, offering strategies to reduce workplace stressors and/or help anesthesia providers maintain effective performance when under stress is an important area for patient safety.

Table 1
Examples of common forms of bias

Name of Bias	Definition	Example
Overconfidence bias	Individuals are overconfident and optimistic in their abilities.	An experienced anesthesiologist induces general anesthesia without using a checklist and is unable to ventilate the patient because both the CO_2 scrubber and backup airway device are missing. The patient becomes severely hypoxic by the time a replacement backup airway device is found.
Anchoring bias	Individuals attach to initial information and do not update based on more recent information.	An obese patient's oxygen saturation (sat) falls slowly to 90% during robotic prostatectomy in steep Trendelenburg position. The anesthetist, convinced that positioning is responsible, increases positive end-expiratory pressure to 10 cm H_2O and is encouraged that the sat increases to 92%. The anesthetist is then relieved for lunch and the relieving anesthetist replaces the finger pulse oximeter sensor with one on the nose and finds the sat is 100%. At the end of surgery, the finger pulse oximeter is found partially dislodged.
Confirmation bias	Individuals selectively gather information that fits their worldview and ignore or dismiss information contrary to their world view.	An anesthetist requests to have the medication cart restocked between cases and is assured it is done. Toward the end of the next surgery, while the surgeons are finishing a laparoscopic procedure with the main room lights off, the anesthetist draws up the paralytic reversal drugs neostigmine and glycopyrrolate. A couple minutes after giving the reversal, the patient becomes bradycardic and remains completely paralyzed. The anesthetist then discovers that the glycopyrrolate bin was accidentally restocked with similar size and color vials of rocuronium (a paralytic drug).
Availability heuristic	Individuals base their decisions on information that is easily accessible instead of correct information.	An anesthesiologist routinely evaluates cardiac health by asking patients if they can climb a couple flights of stairs without getting short of breath. A healthy-appearing patient answers that he can climb stairs without any problem. After inducing general anesthesia, the patient becomes hypotensive and arrests. After successful resuscitation, a more detailed review of the medical record reveals a recent cardiology clearance note that says the patient is high risk with a severe cardiomyopathy but is in optimal shape for surgery.

(*continued on next page*)

Table 1
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Name of Bias	Definition	Example
Escalation of commitment	Tendency to continue with a decision even when it is clearly incorrect	A surgeon persists with robotic assisted laparoscopic surgery, even though there is significant blood loss making it difficult to see what he is doing. He says he is almost done and insists on continuing even after being told that the patient is hypotensive and requiring blood transfusion. He converts to an open approach only after the patient arrests, at which time he discovers a laceration of a major blood vessel requiring vascular surgery intervention.
Hindsight bias	The tendency to believe the outcome of a decision could be predicted after the outcome has already occurred	During an open nephrectomy, a patient starts bleeding profusely and arrests during the 20 min it takes to get blood in the room. The patient is successfully resuscitated but later dies in an ICU. The anesthesiologist blames himself for not insisting that the blood be available in the room before the start of surgery.
Randomness error	Ascribing causal meaning to random events	An anesthesiologist refuses to offer spinal anesthesia to any patient taking herbal supplements after having 1 such patient become paralyzed from a spinal hematoma, even though it is known that herbal supplements do not increase the risk after spinal anesthesia and that this 1 patient probably had spinal arterial-venous malformations responsible for the hematoma.

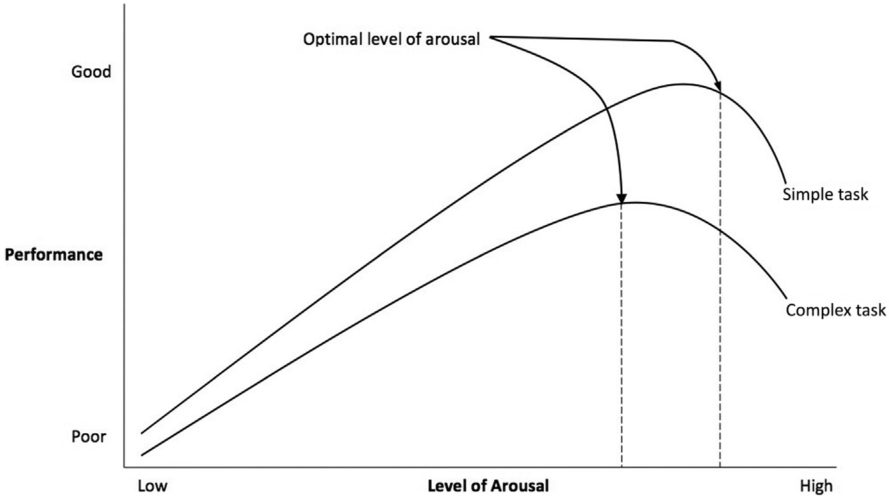

Fig. 2. A graphic representation of the Yerkes-Dodson law demonstrating the relationship between level of arousal and performance during tasks. (*Adapted from* Wickens CD, Gordon-Becker SE, Liu Y, et al. An introduction to human factors engineering, 2nd edition. Upper Saddle River [NJ]: Pearson Prentice Hall; 2004; with permission.)

Workload

Although stressors include environmental as well as psychosocial factors, a prominent stressor is mental workload. The term, *mental workload*, relates the demands of the task to the mental resources of the operator[17] and is an area of HF/E that has a long history of research.[18] The feeling of having “too much to do in too little time” is a simple example of overly high workload and, in turn, may indicate an individual is vulnerable to performance decrements.

Assessing providers’ workload level is an important aspect of evaluating the effectiveness of their workplaces, equipment, and procedures.[19] An initial step to identifying high workload situations is to conduct a timeline analysis.[20] A timeline analysis is a task analytical approach to determine overlap in tasks during any point in time.[21] Although task analytical inspections of this nature can indicate high workload exists, examining task time schedules is only 1 aspect of understanding workload. An individual’s effectiveness at time-sharing tasks can also be altered by factors, such as extensive experience performing the task and/or automaticity (as described previously) as well as which particular mental resources a task demands (eg, visual vs auditory).[1]

A variety of more in-depth approaches to measuring workload exist and have been well tested in domains, such as aviation and, more recently, anesthesia. Workload measurement approaches include inspection of the speed and accuracy of task performance, adding a secondary task to assess availability of unused mental resources, and physiologic measures (from circulatory, respiratory, central nervous [including visual], and endocrine systems) as well as subjective workload ratings provided by the operators themselves.[22] As an example of the effectiveness of this work, Weinger and colleagues[21,23,24] have had multiple successes using a variety of these techniques in the perioperative setting.

PERFORMANCE ASSESSMENT

Performance assessment, the systematic collection of information to diagnose performance, is arguably the most substantial driver to enhancing the quality of health care and patient safety.[25] It is used to determine the competence of clinical care providers, to provide information to health care consumers, and for quality-improvement efforts.[26] Understanding performance and performance variations, which can only be ascertained through assessment, can serve as the scientific foundation for health policy.[27] Ultimately, performance and the subsequent findings from assessment have an impact on 3 distinct groups: patients, clinicians, and employers.[28] Understanding the impact on these groups becomes complex when considering performance assessment within clinical practice. The complexity inherent within performance assessment is due to the dynamic and interdependent nature of health care[29] and the individual variations within patients.[30]

Although performance assessment is invaluable for advancing quality care, it is not a panacea and must be developed and executed according to the science of learning and psychometrics. According to these sciences, there are several considerations that need to be addressed to maximize performance assessment. The first requirement is to consider multiple levels of measurement.[31] Performance can be measured at the individual, team, department, and even organizational levels. The appropriate level is determined by the knowledge, skills, or attitudes being trained and the type of feedback and remediation necessary to improve performance. The second requirement is that performance assessment should consider processes as well as outcomes.[32] Outcomes represent the end result, and they identify the presence of problems. They alone, however, do not provide any insights into how those outcomes were accomplished, the cause of the result, and what strategies are necessary to achieve a different outcome. Patient outcomes are often cited as the cornerstone of performance measurement[25] but focusing exclusively on such outcomes depicts an incomplete picture. Essentially, it is unknown if the outcome was reached through accurate or erroneous processes. Processes, on the other hand, are more descriptive and diagnostic and offer insights and directions for how to address any behavioral changes. The third requirement is to use multiple sources, techniques, and tools for assessing performance.[33] To elaborate, the source of measurement refers to who is conducting the assessment (eg, supervisor, peer, or learner); the techniques and tools refer to the how and what in regards to devices and procedures used to conduct assessments (eg, surveys, observations, or interviews). Multiple sources, techniques, and tools ensure a more robust and comprehensive understanding of performance. The only way to truly diagnose, deconstruct, and rectify every element of performance is by leveraging an assessment program that heavily considers the science behind psychometrics and learning.

One exemplar study of an operating room performance assessment program heavily scrutinized the aforementioned requirements, conducting a team training intervention and evaluation at a large southeastern community hospital. The assessment program was multilevel and focused on processes and outcomes and included multiple sources, techniques, and tools.[34] Specifically, the research team used a multilevel assessment that focused on trainee reactions, trainee knowledge, trainee on-the-job behaviors, and organizational outcomes (eg, patient safety culture). Within this assessment, the processes included team behaviors (ie, communication, leadership, mutual support, and situation monitoring), and the outcomes were represented as patient safety culture. To ensure that multiple sources and measurement tools were used, the team leveraged surveys that participants completed as well as observations that members of the research team performed.

SAFETY AND ACCIDENTS

Medicine is rapidly evolving, with a current paradigm shift regarding the way it conceives of and reacts to errors. In the field of human factors, errors have been looked at as a systemic issue for decades. In other words, the field of HF/E has treated errors as an inherent aspect of risky systems, instead of as solely the failures of individuals or teams operating within the system. This differs greatly from traditional ideas of error in which individuals are blamed for failures, a way of thinking that is outdated and counterproductive in modern systems and organizations.

There are numerous possible reasons that blame has persisted as an aspect of error management. For instance, blaming individuals means that those blaming are assuming they can understand the cause of an error and prescribe only 1 source of that error — the operator or, in this case, the provider involved in the case. As discussed, ascribing causation to random data is a common bias and is likely behind much of the blame that exists in medicine. But as described previously, understanding causation is skewed by views, experiences, memories, and biases. Blame also moves away from uncovering the operational issues that can propagate and make an organization less safe. Most errors arise from couplings between humans, technology, tasks, and the organizational context.[20] Blaming individuals, then, is not only incorrect but potentially counterproductive: punishing providers for committing errors leads to an organizational culture where there is less of a chance of *error reporting* — an absolutely integral aspect of high reliability organizations.[35] Individuals who fear punitive measures do their best to protect themselves in a system that punishes them.

Root cause analyses (RCAs) have become a common investigative method in hospitals and medical systems. Usually RCAs use interviewing techniques after a medical incident and use these data to discover causal factors leading to the mishap. Unfortunately, even the name itself — *root cause* — is problematic. In almost all accidents there are arguably multiple causes, and assuming there is 1 cause only delays the uncovering of other causal factors. In recent years, RCAs have moved away from their name toward a technique called all-cause analysis. Furthermore, research has called for the integration of HF/E professionals into error investigations to ensure ergonomics and cognitive aspects of work are considered in the management and investigation of errors.[36]

SUMMARY

This article attempts to provide a high-level overview of the field of human factors in relation to perioperative medicine. This is in no way a comprehensive view of the science but it is hoped that enough insight is provided to give clinical teams ideas on where they can start solving issues or changing policies to support safety and better patient outcomes. To tie this information together, some investigators have developed models to represent the multiple moving parts that need to be considered in modern-day health care organizations. One example of this is the Systems Engineering Initiative for Patient Safety (SEIPS) model.[37] The SEIPS model is a representation of the various organizational components — people, patients, tasks, technology, and organizational constraints — that in many ways summarize the entirety of applying HF/E across the health care continuum. **Table 2** presents examples of how these different elements may interact to challenge performance in perioperative settings. Thinking about how HF/E principles apply to safe perioperative care, 3 HF/E-informed guidelines for safety are offered.

Adopt Cognitive Aids and Checklists for Complex Tasks

The use of protocols and checklists has become widespread in medicine. These cognitive aids can be key ingredients to supporting thinking and decision making and should be instituted where a large amount of information is transmitted or

Table 2
Potential issues with human performance in perioperative settings

Issue	Definition	Example
Cognitive fixation	Attachment to previous judgments although new information has arrived that should change that judgment	A provider mis-hears a patient state that she drinks 2 bottles of wine per evening, when the patient actually said 2 glasses. Further diagnoses are based on the assumption the patient is alcoholic.
Plan continuation	Adherence to a plan although cues demonstrate that it is not working	A provider team moves forward with a surgery although the patient was exhibiting some comorbid symptoms that could lead to a poor surgical outcome.
Incomplete or incorrect knowledge, skills, or attitudes	Lack of knowledge, skills, or attitudes pertinent to finding a remedy for a particular situation or escalating error	The certified registered nurse anesthetist had not been part of a code blue in more than 5 y and was unsure of exactly what steps to take next.
Novel technology	Introduction of new tools and technology without appropriate training leads to risks that were not previously in the system and also leads to unexpected information as the system reacts in new and different ways.	The new EMR continually led to delays due to unexpected lockouts, difficulty in finding needed information, and lack of a good user interface.
Dynamic fault management	The need to continue attending to ongoing information and tasks as new tasks stack on top due to system failures	A surgeon accidentally cuts an artery during surgery and needs to manage the subsequent blood loss while also attempting to finish the surgical procedure.

Adapted from Dekker S. Patient safety: a human factors approach. Boca Raton (FL): CRC Press; 2011; with permission.

recorded between providers. The more complex a patient case, the more useful these types of tools can become. Although EMRs have been adopted to fill this role, they come with a set of other problems that have made them difficult to adopt and use, especially in the high-stakes and fast-paced environment of perioperative medicine. Through research and design, cognitive aids can be introduced that work along pinch points that cannot be fulfilled by EMRs alone.

Use Error Reporting Systems

Creation of both anonymous and nonanonymous error reporting systems can greatly enhance organizational mindfulness. The use of both systems is important.

Anonymous systems allow for individuals to report their concerns without having to worry about repercussions or punitive actions. This is especially important for organizations that are going through a cultural change, yet are still relying on the human error model. The nonanonymous system allows for follow-up interviews to garner more information around a specific problem. Allowing individuals to have the option of both creates a culture of understanding and keeps the organization on the path to high reliability.

Enhance the Root Cause Analysis Process

Although RCAs are going through quite a bit of change, they can still fundamentally be useful for understanding errors. Understanding that there are multiple causes is the first step to increasing their effectiveness. Furthermore, integration of HF/E consultants can aid hospitals in understanding potential systemic factors, including equipment and technology failures, issues with team coupling, task complexity, or organizational policy — all potential issues that might be missed by using the standard RCA process.

Summary of Recommendations

Consider the cognitive limitations of health care providers and support staff within the perioperative environment. Although they are experts, they still suffer from the same limitations of any human working in a high-stakes, high-risk system. This needs to be considered in the design of their work environment and procedures and appreciated by organizational leadership. Where applicable, cognitive aids, checklists, and so forth should be used to support the cognitive functioning of medical providers.

Understand that humans work within the confines of bounded rationality and that most decisions are made on incomplete information. Organizations should provide support through decisions aids, safety policies, and cognitive aids to support provider thinking and reduce bias. Antibias training could also facilitate better decision making.

Understand that human error is usually not a satisfactory explanation for why medical errors occur. Instead organizations need to adopt a policy that appreciates the complexity of medicine and values that providers do not want to harm their patients. Human operators (ie, providers) are at the sharp end of the system and usually stumble on errors, not because they are incompetent but because the system is imperfect and risky. Through utilization of error reporting systems and investigations that appreciate systemic factors, medicine can learn about deeper rooted systemic factors and work on fixing them rather than finding a scapegoat and leaving the problem in place.

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